

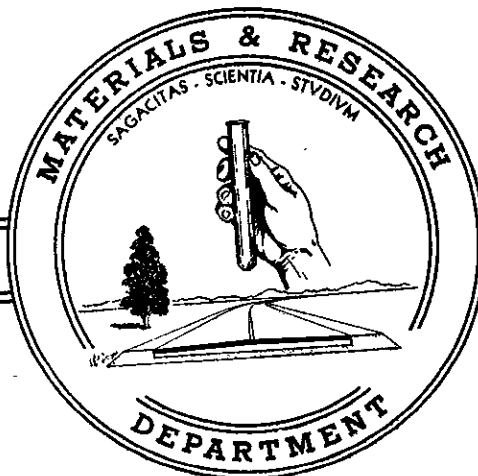
STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS



A REPORT ON
THE INVESTIGATION OF THE CAUSES OF CORROSION OF
WATER PIPE AT THE PASO ROBLES SCHOOL FOR BOYS,
WITH RECOMMENDATIONS FOR CORROSION PROTECTION.

57-02

May 1957



State of California
Department of Public Works
Division of Highways
Materials and Research Department

May 24, 1957

Cathodic Protection System
Paso Robles School for Boys
Lab. Project Auth. 72-S-6098

Mr. Anson Boyd
State Architect
Division of Architecture
1120 N Street
Sacramento, California

Attention: Mr. C. A. Henderlong
Principal Mechanical and Electrical Engineer

Dear Sir:

Submitted for your consideration is:

A REPORT ON
THE INVESTIGATION OF THE CAUSES OF CORROSION OF
WATER PIPE AT THE PASO ROBLES SCHOOL FOR BOYS,
WITH RECOMMENDATIONS FOR CORROSION PROTECTION.

Study made by Structural Materials Section
Under general direction of J. L. Beaton
Work supervised by L. S. Hannibal & R. F. Stratfull
Report prepared by R. F. Stratfull

Very truly yours,



F. N. Hveem
Materials and Research Engineer

RFS:mw
cc: JWTrask
Irving Schultz
ODGreenwood

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I. INTRODUCTION

On March 22, 1957, Mr. C. A. Henderlong, Principal Mechanical and Electrical Engineer, requested by letter that the Materials and Research Department perform a corrosion survey at the Paso Robles School for Boys, under Work Order Number 3805GC-18.

Historically, the bulk of the water piping system at the school was installed by the U. S. Army in 1943. The present school was constructed in 1953. Pronounced leakage due to corrosion has developed during the last three years. During the week of April 1, 1957, representatives of the Materials and Research Department carried out the requested survey of the water lines, the purpose being to determine the probable cause of the corrosion and to recommend an effective and economical method of dealing with the problem.

II. SUMMARY

The field corrosion survey of the underground pipe network at the Paso Robles School for Boys, which included visual examination and measurements of pipe to soil potentials as well as measurements of earth resistivities, led to the following conclusions:

The external corrosion of the water lines is caused by typical soil induced galvanic action. This type of corrosion is the result of pipes of dissimilar metals being electrically connected in similar soils, and conversely, similar metallic pipes connected together in dissimilar soil conditions.

Evidence, as indicated by the various electrical measurements, confirms that, depending on the location, cast iron pipe is causing the corrosion of adjacent steel pipe, that concrete embedded electrical conduit is causing the corrosion of cast iron pipe, and that steel pipe in a high resistivity soil is causing the corrosion of steel pipe in low resistivity soil.

In general, it is recommended that an impressed current cathodic protection system be installed and, if necessary, galvanic anodes be considered for the protection of any electrically shielded areas. Also, that all buried metallic structures be electrically connected to the water system.

The estimated cost for cathodic protection in excess of 10,000 linear feet of pipe is estimated at approximately \$4,500.

Detailed recommendations are on page 11.

III. TESTS

A. Pipe to Soil Measurements

The discharge of electrical current from a corroding structure can be detected by the electrical field created by the corrosion currents.

By means of a high impedance voltmeter and a standard copper sulfate half-cell, the piping system was checked for locations of galvanic current discharge or accumulation.

The results of this potential survey are shown on Exhibit No. 1, Equipotential Contours.

As indicated by the potential measurements, the water lines most prone to corrode and which are corroding are near the laundry and administration buildings. Also, the measurements indicate that future leaks in the water system are most prone to occur in the various laterals which service the dormitories.

The stability and reproducibility of the potential measurements indicate that the corrosion problem is typically galvanic and is not caused by stray D. C. currents. This does not exclude 60 cycle A. C. currents which can induce corrosion under certain conditions, but in this case do not appear to have any significant effect.

B. Electrical Resistivity of the Soil

Basically, the corrosion of metals in soil requires that moisture, a soluble mineral, and oxygen from the air be present for the electrochemical corrosion process to function. The magnitude or intensity of electrical current which can flow through the soil (electrolyte) depends to a major extent upon the soluble mineral content and the electrical resistance of the soil.

The electrical resistivity of the soil formations at the Paso Robles School for Boys is shown on Exhibit 2, Equipotential Contour Map.

As indicated by the resistivity measurements, the soil varies from 600 ohm cm. to 30,000 ohm cm.

The resistivity of the soil adjacent to the laundry building, where the greatest number of leaks in the water pipe have been experienced, is approximately 1,000 ohm cm. or less. According to the following chart, the soil is moderately corrosive, and the earth exposed pipe in this area is reaching the end of its normal life span.

The August 1931 issue of Western Gas presents the following classification of soil corrosivity as related to the specific electrical resistance of such soils:

<u>Resistivity - ohm cm.</u>	<u>Corrosivity</u>
0 - 400	Severely corrosive
400 - 1200	Moderately corrosive
1200 - 4000	Mildly corrosive
4000 - 10000	Slightly corrosive

<u>Resistivity - ohm cm.</u>	<u>Probable Life of Bare Steel Pipe in Years</u>
0 - 1000	0 - 9
1000 - 2500	9 - 15
2500 - 10000	15 or more

C. Miscellaneous Tests

Current flow measurements were made at the main propane tank near the laundry building. The ground wire, which runs from the propane tank to the galvanized chain link fence, was disconnected and a direct current ammeter was inserted. The measurement of a flow of direct current indicated that the fence posts were corroding. The measured current flow was 25 milliamperes.

Measurements were also made near the boiler room to determine if there were existing electrical interconnections between the reinforcing steel, the electrical conduit which is embedded in concrete, and the water lines. One lead of the voltmeter was connected to the water line, and the other lead was initially connected to the reinforcing steel, and then to the electrical conduit. A maximum voltage difference of 10 millivolts was found between the water pipe and the conduit, and likewise between the water pipe and the reinforcing steel. The voltmeter was then electrically connected in between the electrical conduit and the reinforcing steel. There was an insignificant indication of voltage difference.

The lack of a significant voltage difference between the pipes indicated that the water lines, electrical conduit, and the reinforcing steel were electrically interconnected.

As a further check on the electrical interconnection, a steel rod was driven in the ground. One side of the voltmeter was left connected to the steel rod. The other terminal of the voltmeter was progressively connected to the water pipe, to the electrical conduit, and then to the reinforcing steel. The steel rod was approximately 0.4 volts anodic to the three test sections. This test also confirms that the reinforcing steel, electrical conduit, and water system were all interconnected. The

anodic potential of 0.4 volts also indicates that if the steel rod should remain in the ground and be left electrically connected to the water system, it would soon corrode due to the galvanic action.

IV. DISCUSSION

A. Corrosion Causes

As stated in the Summary, page 1, the general causes of corrosion to the water system at this institution are due to galvanic currents set up within the soil, where the soil functions as an electrolyte. The difficulties which have appeared in a number of locations are due to damaged or poor application of the protective coating on the pipe system during installation, or breakage and failure of same since installation. The resultant exposed areas of bare metal pipe experience higher current concentrations over a smaller surface area than would be encountered with a pipe system which was entirely bare. These highly corrosive current densities, if anodic, usually lead to rapid corrosion. The situation is aggravated by the use of thin wall pipe.

A possible secondary difficulty is introduced by the occasional discontinuities of the various underground piping systems. In practice this occurs most commonly where a Dresser coupling makes a poor connection between two pipe sections, either due to a layer of scale or the asphalt coatings involved. The galvanic currents set up in the entire piping system may partially leave the pipe in the vicinity of such a coupling, make a local detour through the soil and return through an exposed area or wrapping break to the next section of pipe. These points of current departure about a high resistance couple sets up electrolysis which is as detrimental as regular galvanic action.

Thus cathodic protection, to operate both satisfactorily and effectively, must have all high resistance couples or discontinuities eliminated from the system, and should be maintained at a sufficient potential of 0.85 volts negative to a copper sulfate half-cell over the entire system to discourage any local areas of corrosion.

From the economic standpoint approximately 500 feet of well coated 8" steel piping in 1000 ohm cm. soil can be cathodically protected from corrosion, employing one magnesium anode having a 10 year life, for approximately \$50. In comparison to the high costs of water line replacement employing cast iron or transite piping, the use of cathodic protection is well worth consideration.

B. Anticipated Pipe Failures

Previous to 1954, no record was kept of the total amount of leaks in the water system at the school. However, from 1954 to 1957 there have been 43 leaks in the water system which have required attention. Of the 43 leaks, 25 have been reported to have occurred near the laundry and boiler room. Insofar as an accurate leak record has been maintained since 1954, it was considered expedient to use this record to predict future difficulties. Thus Exhibit III, Total Water Leaks Due to Corrosion Against Time, was prepared. This indicates that without preventive measures there will be 41 additional water leaks due to corrosion in the year 1957. This correlation assumes that the slope of the curve will not be materially affected by additions or modifications, other than the recommended remedial measures.

However, as there may exist an alternative possibility of replacing the corroding water lines at the laundry and administration building with corrosion resistant transite or cast iron pipe, Exhibit IV, Water Line Leak Frequency with Partial Corrosion Protection Methods, was prepared to determine the possible frequency of anticipated leaks in lines elsewhere than in the areas of possible pipe replacement.

This Exhibit IV indicates that there will undoubtedly be 9 additional leaks in 1957, and 19 additional leaks in such line during the year 1958. Therefore, any partial repairs to the water line in the vicinity of the laundry and administration buildings will not solve corrosion problems in other parts of the system. Partial methods of replacement will only forestall the resumption of the present rate of leaks until 1959, but a replacement of the most afflicted water lines in conjunction with a suitable cathodic protection system should curb practically all corrosion leaks.

C. Type of Protection

From the tests and visual examination of the installation, it is impractical to electrically insulate the water system from other piping or building structures to inhibit corrosion. It is specifically recommended that the whole underground system (excluding the line to the local airport) be brought under complete cathodic protection. This would eliminate any localized condition which would remain if cathodic protection was limited. The piping of the system is corroding in too many locations.

An impressed current system of cathodic protection is the most desirable, since it permits some flexibility in control. The wide variations of electrical resistivity in the soil indicate that a system of galvanic sacrificial anodes would not be suitable, as such electrodes do not

function well in areas of high resistivity soil. However, due to the possibility of electrical shielding of some portions of the piping by buildings, and due to the lack of a 110 volt supply in some areas, galvanic anodes may have to be resorted to over a portion of the system.

D. Application and Installation of Cathodic Protection

The application and installation of cathodic protection must be performed with care. Otherwise, accelerated corrosion of some piping may be inadvertently caused. Therefore, before cathodic protection is applied, the piping system should be checked for electrical continuity.

Where electrical discontinuity of the piping system is located, the pipe and Dressler coupling should be uncovered and electrically bonded together.

Insofar as no recommendations have been made to attempt to electrically bond all of the Dressler couplers in the system, there may be a minor number of failures of the couplers after cathodic protection is placed in operation.

The Tentative Specifications for the rectifier are considered adequate to give complete cathodic protection to the piping system, being selected from mathematical assumptions. It is possible that a more economical size of rectifier could be chosen after an actual field test of current distribution from the installed anode ground bed.

After the cathodic protection is installed, it should be periodically checked for operation. Standard check points should be established by the design or field engineer, and measurements should be made by the maintenance division, or others, weekly for the first six weeks of operation. A monthly check thereafter would be sufficient. The check on the operation of the system would not take more than two hours.

The operational check of the system would entail the logging of the rectifier output voltage and current, as well as four or five pre-selected points at which pipe-to-soil potentials are measured.

However, at the conclusion of the first month of operation, this laboratory, or others, should make an inspection of the system to check the operation of the rectifier, make a potential survey, and, more important, ascertain if the piping is electrically continuous. This should require a maximum test and evaluation period of 3 days.

V. CONCLUSIONS

The corrosion of the water lines is the result of galvanic corrosion, which is induced by soil conditions and dissimilar metallic piping.

If cathodic protection is not installed at the institution, approximately 40 additional leaks can be anticipated in 1957 due to corrosion. The placement of new or additional pipe will affect the anticipated number of additional leaks, but will not prevent future leaks.

Cathodic protection by impressed currents is the most practical means of alleviating this corrosion. However, field conditions are such that sacrificial galvanic anodes may have to be installed in certain areas in conjunction with impressed current electrodes.

The suggested methods and tentative specifications for the cathodic protection installation are outlined in the following two sections.

VI. RECOMMENDATIONS

1. That an impressed current cathodic protection system be installed in conjunction with galvanic anodes for corrosion alleviation.
2. That, as indicated on the equi-resistivity contour map, the rectifier should be placed in the gymnasium, or other suitable location which will adequately protect the rectifier from direct exposure to the sun or from vandalism. The proposed locations for the anodes are also indicated on the equi-resistivity contour map.
3. That the institution's 8" water system be electrically insulated from a private system which services the Paso Robles Airport.
4. That, at the conclusion of the installation of the proposed cathodic protection system, an equi-potential contour map be made of the final pipe-to-soil potential while under cathodic protection.
5. That pipe-to-soil measurements be made of the electrically insulated 8" water line to the airport to determine if this line is adversely affected by the cathodic protection system. The potential of this insulated line should not be affected by the State's cathodic protection system.
6. That, if any buried utility lines such as telephone or water, traverse the general area of the institution, officials of

the interested parties should be notified of the State's intentions. Proper tests should be performed in conjunction with the interested parties to determine if the cathodic protection system at the school will affect such distribution systems.

7. That any buried metallic structure, such as chain link fence, should be electrically connected to the piping system so as to receive cathodic protection.
8. That the installation of the anodes and wiring be performed by contract or by day labor.
9. That the final rectifier sizes be selected at the conclusion of a field test performed to establish the current distribution of the anode ground bed.
10. That the piping systems be checked for electrical continuity prior to the application of cathodic protection, as well as after, as noted below in recommendation No. 18.
11. That all electrical discontinuities of the piping system be electrically bonded.
12. That Dressler couplings, valves, or other metallic objects which are located at an electrical discontinuity, shall be electrically bonded to the piping system.
13. That any repair, connection, or dissimilar metal which is connected to the piping by this work shall be heavily coated by "Ozite" or an equally effective protective coating, being so installed as to prevent direct metallic contact to the soil.
14. That pipe-to-soil measurements be made and recorded at selected points at weekly intervals for the first six weeks of operation and monthly thereafter.
15. That the output voltage and current of the rectifier shall be recorded at one-week intervals for the first six weeks of operation and monthly thereafter.
16. That the output of the rectifier shall be adjusted, as required, to maintain the piping system at least 0.85 volts negative to a copper sulfate half-cell.
17. That the piping system shall not exceed 3.0 volts negative to a copper sulfate half-cell.
18. That, at the conclusion of the first month of operation of such a cathodic protection system, a check be made of the electrical continuity of the piping system.
19. That the Materials and Research Department be informed of any changes in rectifier output or the installation of new piping after the cathodic protection system is installed.

20. That the Materials and Research Department be immediately informed of any additional leaks in the piping system after the installation of the Cathodic Protection System.
21. That at the conclusion of the first month of operation of such a cathodic protection installation an equipotential survey of the system be made.
22. That at the conclusion of the first month of operation of the cathodic protection installation the output of the rectifier be altered, if necessary, to compensate for polarization of the piping.
23. That at yearly intervals a corrosion survey be made of the piping system to substantiate the effectiveness of such cathodic protection.
24. That at yearly intervals the piping system be checked for electrical continuity.
25. That if the Materials and Research Department does not perform the necessary yearly surveys that the Materials and Research Department receive a copy of such surveys.

VII. TENTATIVE SPECIFICATIONS

Selenium Rectifier or Equal

Input - 110 or 220 volt, single phase, output variable to 30 volts D.C. at 25 amperes. Regulation of D.C. output from 0 to 30 volts in a minimum range of 10 steps of equal voltage.

Specifications should include that the rectifier should perform satisfactorily under maximum output when air temperature is 130°F.

Instrument should include both D.C. ammeter and voltmeter to cover the output range of rectifier. Overload and thermal protection for the rectifier should be provided.

Specifications should also specify if the instrument is to be pole or rack mounted.

Suggested Suppliers

Harco Corporation
P. O. Box 7026
16901 Broadway Avenue
Cleveland 28, Ohio

Brance Krachy Company
4411 Navigation Blvd.
Houston, Texas

Suggested Suppliers (Contd.)

Electrical Facilities, Inc.
4224 Holden Street
Oakland, California

Cathodic Protection Service
310 Thompson Building
Tulsa, Oklahoma

Sabins-Dohrmann Co.
522 Catalina Blvd.
San Diego 6, California

Pipe Line Anode Corp.
Box 996
Tulsa, Oklahoma

Frost Engineers Service Co.
P. O. Box 767
Huntington Park, California

Impressed Current Anodes

National graphite anodes or equal. Anode to be 3" x 60" with No. 8 T.W. or equal lead wire attached and water sealed 5' of length.

Anode Backfill Material

"National" BF-3 backfill consisting of graphite particles and an alkalizer or equal.

Placement of Impressed Current Anodes

Impressed current anode beds shall be constructed at the locations designated by the engineer in the following manner:

1. Auger, or otherwise construct anode holes of 12 inches diameter and 10 feet below the grade of the original ground.
2. Backfill this hole with BF-3 or equal backfill material to a well compacted depth of one foot (9 feet below grade).
3. Place and center graphite anode in hole.
4. Continue to place and compact backfill material in layers not exceeding one foot, until the anode has a minimum of one foot of backfill cover.
5. A sand or otherwise non-clay porous material is to be used to completely backfill the anode installation. Top soil may be used within 6" of original ground level for the purpose of growing lawn, et cetera.

Wiring

1. Stranded anode lead wire shall be 600 volt RR A.W.G. size No. 2 or equal.
2. All splices of the anode lead wires to the main feeder lines shall be made by solder joints, brazing, or the Cadweld Process or equal. The soldered splices shall be adequately protected from current leakage through the soil by using a Scotchcast Splicing Kit containing No. 4 resin.
3. The main feeder line from the rectifier to the anode beds shall be embedded at least one foot below the original ground grade or to a depth that will insure its protection from accidental severance by cultivation or excavation.

If any anticipated major problem may occur of rodents severing the main feeder line or the insulation of such, the cable shall be protected by placing same in a suitable coverage of concrete or metallic sheath.

Sacrificial Anodes - Galvanic

Dow Type 32-D galvo-pak (Galvo-mag) magnesium anodes or equal with 10 foot lead wire.

Placement of Galvanic Anodes

1. Auger 10" diameter hole 5' 6" deep, 3' distant from the pipe.

2. Place anode in hole and compact soil around anode.
3. Moisten anode backfill.
4. Anode lead wire, which is to be buried 1' below ground, should be brazed or electrically connected to the pipe by either the Cadweld Process or equal.
5. If Cadweld Process is not employed, the following procedure is recommended for connecting the lead wire to the pipe:
 - (a) Braze 70 amp. or equal copper lug to pipe.
 - (b) Solder anode lead wire to copper lug.
 - (c) Tape exposed wire with Scotchrap No. 50 or equal, from the solder lug, to include a minimum of 6" insulated wire beyond the soldered joint.
 - (d) Completely coat the splice and electrical pipe connection with "Oakite" or Scotchkote Brand Electrical Coating or equal.
6. Backfill hole with moist earth compacted in 6" layers.

VIII. CATHODIC PROTECTION - COST ESTIMATE

Cathodic Protection Rectifier	\$ 300.00
20 - 3" x 60" Regular Graphite Anodes	200.00
6 - Type 32-D (Galvo-Mag) Galvo-Pak Magnesium Anodes	138.00
Lime Treated Coke Breeze 4800 lbs.	300.00
1000 L.F. A.W.G. No. 2 R.R. wire or equal	200.00
Misc. wire and connectors	150.00
Installation of anodes	400.00
Installation of wiring	1,000.00
Installation of rectifier	200.00
Engineering	<u>1,000.00</u>
Sub total	\$ 3,888.00
+15% contingencies	<u>583.20</u>
	\$ 4,471.20
say	\$ 4,500.00

EXHIBIT III

TOTAL WATER LEAKS DUE TO CORROSION AGAINST TIME

359-63
SEMI-LOGARITHMIC
KEUFFEL & ESSER CO.
MADE IN U.S.A.
2 CYCLES X 140 DIVISIONS

ACCUMULATIVE LEAKS

Projected Leak Curve

Note: Records of leaks
were not kept prior
to March 1954

STATE OF CALIFORNIA DIVISION OF HIGHWAYS
MATERIALS & RESEARCH DEPT.

1954 1955 1956 1957 1958

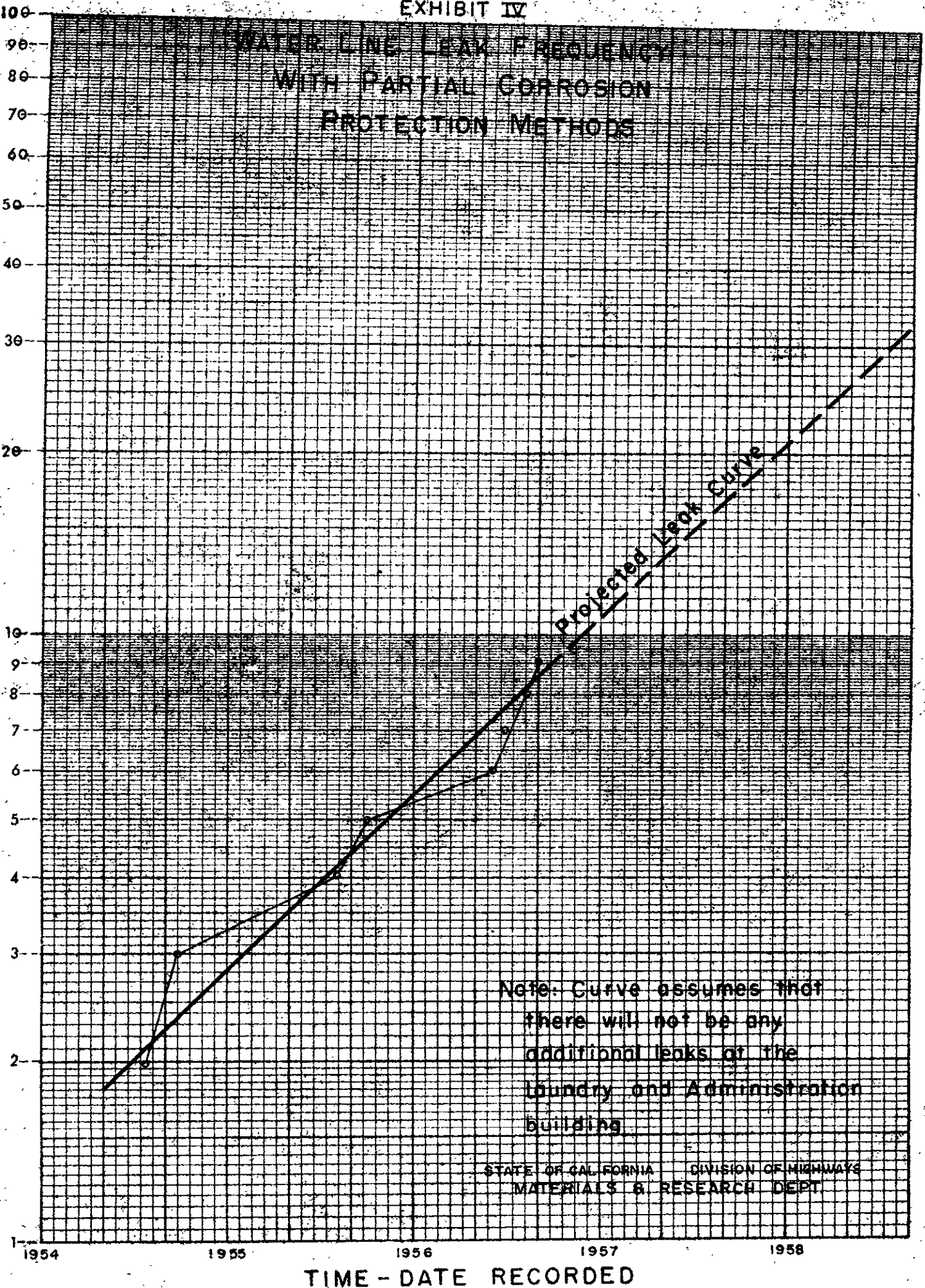
TIME - DATE RECORDED

EXHIBIT IV

WATER LINE LEAK FREQUENCY WITH PARTIAL CORROSION PROTECTION METHODS

ACCUMULATIVE LEAKS

No. 911-44 Semi-Logarithmic
2 cycles x 10 to the inch, 5k lines centered
The A. Lietz Co., San Francisco
Made in U.S.A.



CORROSION TECHNOLOGY DEFINITIONS

Electrolysis:

The production of chemical change in an electrolyte resulting from the passage of electricity.

Galvanic Cell:

A cell made up of two dissimilar conductors in contact with an electrolyte, or two similar conductors in contact with dissimilar electrolytes. The area involved may be microscopic in size, or involve an area of many miles of pipe.

Local Action:

Corrosion caused by local cells on a metal surface.

Long Line Current:

Current flowing through the earth from an anodic to a cathodic area which returns along an underground metallic structure. Usually used only where the areas are separated by considerable distance and where the current results from concentration cell action.

Concentration Cell:

An electrolytic cell, the emf of which is due to a difference in concentration of the electrolyte or active metal at the anode and cathode.

Stray Current Corrosion:

Corrosion caused by current through paths other than the intended circuit, or by any extraneous current in the earth.

High Resistance Couples:

A high resistance joint in a pipe, for example, may cause some of the current carried by the pipe to bypass through the earth and damage the anodic side of the joint.